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14. ABSTRACT
This is a summary report on the SWARMing research with milestones.
Several novel control propositions are developed and stability under the delayed communication channels are explored.

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Report Title

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ABSTRACT

This is a summary report on the SWARMing research with milestones.
Several novel control propositions are developed and stability under the delayed communication channels are explored.

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Reporting period : July 2009 – June 2010

SWARM BEHAVIOR DURING CONFLICT: FROM BIOLOGICAL TO ENGINEERED SYSTEMS

Personnel and Recruitment

We have a biology-engineering collaboration effort that has been going on from the beginning (Prof. Adams from Evolutionary Biology, is a team member)

- A **PhD level graduate student** who joined the group in Fall 08: **Rudy Cepeda Gomez**, is continuing his development in swarming. He has already passed doctoral qualifiers (in February 09). And presently succeeded in two journal articles that are in print (one for J. of Vibration and Control and the other is for IET Control Theory & Applications),studying the robust nonlinear control of SWARMS under conflict, including the communication delays. He is actively developing decentralized control algorithms for swarm consensus under delayed communication channels and switching irregular topologies. On this line he has two journal articles submitted for review [1,2]:
- An **MS level student, Mark Bacon**, has developed 2v1 herding schemes and heuristics rules for a stable multi-agent swarms herding a multi-agent evader swarm. He has participated in a journal article, and he has submitted one journal paper (on his own) [3]. He is expected to graduate in Fall 2010 semester.

  Mark has also presented a paper on hostile swarm interactions at the 2nd DSCC in Oct. 2009, Hollywood, CA. He also won a **third place award in the graduate research competition** at UCONN (2010).

- Part-time **doctoral studen**t, **Daniel Sierra Bueno,** who joined us in the Summer of 2008 was instrumental in 3 journal articles. [4-6]. He is currently a faculty at UIS (Universidad Industrial de Santander) in Columbia.

Research progress

Primary elements of progress are listed in the following categories and explained in the attached documents in detail.

The progress is in three axes of SWARM research

1. We have been looking at the **cross-breeding between biology and engineering** as it was shared with SWARM researchers at the Block Island Workshop (June 2009). Summary presentation is available on URL http://alliance.seas.upenn.edu/~swarms/cgi-bin/swarming09/index.php?n=Main.Presentations. Several interesting topics came into recognition and they have been publicized in journal articles listed below as well as in the conferences for rapid dissemination.

A) Stabilization of hostile swarming dynamics. Several strategies are suggested under the presence of nonlinear interaction force structures (attraction-repulsion-detection-control). Several novel elements came out of this line:

A1) Two-stage operation scheme is introduced inspired from the biological observations. An **approach phase** (where the pursuer swarm tries to position its centrode close to that of the evader swarm's), followed by the **individual pursuit phase** (where the assigned pursuer-evader dynamic prevails). One of the highlights is the introduction of a "**transition function**" to stitch these two phases in a smooth manner. [4-6].

A2) A novel utilization of Lyapunov's method by the introduction of both **stepwise** (impulsive) and **phased-out** (window type) energy dissipating controls [4,5]. This logic guarantees a robust evader capture within a desired time.

A3) Region following swarms are introduced using an improved version of Sliding Mode Control logic [3]. SMC is the tool which spreads the agents in a given geometric target (typically a circle or an ellipse) .

A4) Sliding mode-based robust control is introduced for a guaranteed capture of the evaders. The key feature in this effort is that the evaders have bounded but unknown turning capabilities to escape from capture [7].

Several conference and journal articles resulted from this line of studies. All of them are uploaded on the ARO-Extranet periodically. Below is a list of archival journal articles in this area [4-6].

B) Group herding control between multiple groups of pursuers v. evaders. This is a weakly studied area in SWARMING literature. We use our own region following schemes (A3) to deploy the pursuer swarms as paddles guiding the evader swarms towards a desired (fixed or moving target). A three-phase control is constructed for this staging-herding and retaining. [3].

C) Consensus for SWARMS with irregular and switching communication topologies and DELAY. This development is cracking into a poorly understood domain of swarming, the time delayed and irregular topologies in the distributed control. Stability

assessment is very complex and we use our own **CTCR (Cluster Treatment of Characteristic Roots)** Paradigm for this approach. The first results have been very promising and well received by the systems community. I gave a plenary lecture on this topic at the IFAC-Time Delay Systems Workshop, this June in Prague (see http://tds2010.fs.cvut.cz/)

We also have two journal articles in review [1,2] on this topic, as well as a conference paper (CDC 2010) [2]. The interesting outcome is that we are able to tackle swarm consensus problems with a very large membership counts while their communications with the neighbors is time delayed. As a consequence we have a stabilizing mechanism to tune the control parameters as well as the communication delays.

2. An on-going activity: development of a **computationally efficient simulation platform** in MATLAB. This study is to create a new simulation platform to animate the evolution of swarms with hundreds of agents. SIMULINK s-function utilities are created to achieve this. Various nonlinear interaction rules are possible to incorporate as the user desires. The code can currently handle few dozens of agent swarms with real-time animation capability. We have several case studies which demonstrate the mission clearly. They are viewable at the URL http://www.engr.uconn.edu/alarm/files/swarm.html . We are going to make this code available to the SWARM community by the year's end.

Publications

1. "Stability analysis for the group dynamics consensus with time delayed communication", (R. Cepeda Gomez, N. Olgac), in review, J. of the Franklin Institute, 2010.

2. "An Exact Method for the Stability Analysis of Linear Consensus Protocols with Time Delay", R. Cepeda-Gomez and N. Olgac, in review for IEEE, Tran. on Automatic Control, 2010. This paper is accepted for presentation at the CDC 2010, in Atlanta.

3. "Robust Region-tracking for Multi-agent Systems Using Sliding Mode Control" (M. Bacon, N. Olgac), in review, Robotics and Autonomous Systems, 2010. Also to be presented at the DSCC 2010 in Boston.

4. "Swarm Coordination Under Conflict", (D.A.Sierra, P. McCullough, E. Adams, N. Olgac), in print, Asian J. of Control, 2010.

5. "Swarm Coordination under Conflict and Use of Enhanced Lyapunov Control", (D.A.Sierra, P. McCullough, N. Olgac, E. Adams) accepted, ASME - J. of Dynamic Systems, Measurements and Control, 2010.

6. "A Lyapunov Treatment of Swarm Coordination Under Conflict", (P. McCullough, M. Bacon, N. Olgac, D.A.Sierra, R. Cepeda-Gomez), in print, J. of Vibration and Control, 2010.

7. "Application of Sliding Mode Control to Swarms under Conflict", (R. Cepeda-Gomez; N. Olgac; D. A. Sierra), accepted, IET Control Theory & Applications, 2010.